

AIRCRAFT SHOCK STRUT HAVING A FLUID LEVEL MONITOR

Field of the Invention

The present invention relates to aircraft shock struts for absorbing and
5 damping shock forces, such as during landing, taxiing or takeoff, and particularly
to an "air-over-oil" shock strut.

Background of the Invention

Shock absorbing devices are used in a wide variety of vehicle suspension
systems for controlling motion of the vehicle and its tires with respect to the
10 ground and for reducing transmission of transient forces from the ground to the
vehicle. Shock absorbing struts are a common and necessary component in
most aircraft landing gear assemblies. The shock struts used in the landing gear
of aircraft generally are subject to more demanding performance requirements
than most if not all ground vehicle shock absorbers. In particular, shock struts
15 must control motion of the landing gear, and absorb and damp loads imposed on
the gear during landing, taxiing and takeoff.

A shock strut generally accomplishes these functions by compressing a
fluid within a sealed chamber formed by hollow telescoping cylinders. The fluid
generally includes both a gas and a liquid, such as hydraulic fluid or oil. One type
20 of shock strut generally utilizes an "air-over-oil" arrangement wherein a trapped
volume of gas is compressed as the shock strut is axially compressed, and a
volume of oil is metered through an orifice. The gas acts as an energy storage
device, such as a spring, so that upon termination of a compressing force the
shock strut returns to its original length. Shock struts also dissipate energy by
25 passing the oil through the orifice so that as the shock absorber is compressed or
extended, its rate of motion is limited by the damping action from the interaction
of the orifice and the oil.

Over time the gas and/or oil may leak from the telescoping cylinders and
cause a change in the performance characteristics of the strut. Presently, there is
30 no reliable method of verifying the correct servicing parameters of aircraft shock
struts. While gas pressure can be readily monitored, it cannot be readily
determined if a loss in gas pressure arose from leakage of gas alone or from

leakage of both gas and oil, unless external evidence of an oil leak is noticed by maintenance personnel. If a low pressure condition is detected in the absence of external evidence of an oil leak, maintenance personnel heretofore would restore the gas pressure to a prescribed level by adding gas. This, however, eventually
5 leads to degraded performance of the shock strut if oil had indeed escaped from the strut. Even if evidence of a oil leak is observed, maintenance personnel cannot easily determine how much oil remains or whether the remaining amount of oil meets specifications or is acceptable for operation.

Two methods can be used to determine whether a strut has the correct
10 pneumatic charge. One method is to jack-up the aircraft to take the weight off of the struts such that each strut is fully extended. The proper pressure that corresponds to the extended position of the strut is a known value. In the other method the pressure is measured with the aircraft supported by the strut using a pressure gauge, and the stroke is measured to determine the extension of the
15 strut. Variations in the weight of the aircraft and the position of the center of gravity cause the strut to sit at a variety of strokes in this situation. A look-up table or chart is then used to verify that the stroke and the pressure match an acceptable value. Since jacking the aircraft is rarely done and is very time consuming, the method of verifying the pressure with the aircraft supported by the
20 strut in a static position is most commonly used. This latter technique, however, is not a very reliable way to check the oil level.

The only reliable way to know that the oil level is acceptable is to vent the pneumatic charge and pump oil through the strut to ensure a proper oil level. The strut can then be re-inflated with gas to the proper pressure. This operation takes
25 a significant amount of time, and as a result maintenance personnel may skip this step and only correct the pressure by adding or venting gas. In addition, neither technique enables detection of the oil level while the aircraft is in flight.

Summary of the Invention

The present invention provides a shock strut that includes a probe for
30 detecting a condition of a liquid level in the strut. Thus maintenance personnel, or perhaps even a flight crew, can readily ascertain whether the liquid level in the strut is within acceptable parameters and can monitor the liquid level for leaks. In

addition, the present invention provides a sensor assembly having such a probe that can be removed from the strut as a unit, thereby facilitating repair and maintenance of the sensor assembly.

In particular, the present invention provides an aircraft shock strut that
5 includes a cylinder, and a piston telescopically movable within the cylinder. The piston and the cylinder define a sealed chamber that is partially filled with a liquid and partially filled with a gas. The strut also includes at least one probe associated with the chamber for sensing a condition of a level of liquid in the chamber.

10 The strut may be part of a system that further includes a processor in communication with the probe for processing a signal from the probe related to the level of liquid in the chamber. The strut may include a cable that passes through a wall of the strut for connecting to the probe, such as an optical fiber cable. A fitting assembly engages the cable and seals a passage through the
15 strut wall to the chamber. The fitting assembly preferably includes a plug molded around the cable and a retainer for holding the plug in sealed relationship with a through passage in the strut. The cable may include at least one optical fiber or a plurality of optical fibers that have transversely spaced apart, coextending portions, each of which is surrounded in sealed relationship by the plug that has
20 been molded thereto. The shock strut may include two probes, a first one of which detects a first condition of the liquid level and a second one of which detects a second condition of the liquid level.

The probe and cable may be assembled together as a unit that is removable as a unitary piece from the strut. The strut may also include a guide
25 tube mounted within the chamber so that the unit at least partially extends through and is located by the guide tube.

The present invention also provides a method of monitoring a condition of a liquid level in an aircraft shock strut. The method includes the steps of receiving a signal related to the liquid level from at least one probe of a shock strut, and
30 processing the signal to determine a characteristic of the liquid level in the strut.

The monitoring system provided by the present invention also may allow personnel removed from the landing gear and the strut, such as a pilot, to check a

condition of the liquid level, such as whether the level of liquid is below a specified minimum in the strut, either after takeoff and before the landing gear is retracted or after extending the strut for landing but before the aircraft touches down on the runway. At that point the strut is not under load and is fully extended, and reliable
5 readings can be taken that will indicate whether the liquid level in the strut is acceptable. In addition or alternatively, the data may be stored for later retrieval by maintenance personnel.

The foregoing and other features of the invention are hereinafter fully described and particularly pointed out in the claims, the following description and
10 annexed drawings setting forth in detail a certain illustrative embodiment of the invention, this embodiment being indicative, however, of but one of the various ways in which the principles of the invention may be employed.

Brief Description of the Drawings

FIG. 1 is a schematic elevation view of a simplified landing gear assembly
15 incorporating a shock strut in accordance with the present invention.

FIG. 2 is a partial cross-sectional view of a shock strut provided by the present invention.

FIG. 3 is an enlarged cross-sectional view of an upper end of the shock strut of FIG. 2 in area A.

20 FIG. 4 is an enlarged cross-sectional view of a fitting in the shock strut of FIG. 3 in area B.

Detailed Description

FIG. 1 presents a simplified aircraft shock strut 10, shown mounted at an upper end to an aircraft structure 20 by an attachment member 22. Any of a
25 number of types of struts (or shock absorbers) may be used in accordance with the present invention, provided that they involve an internal working fluid. A wheel assembly 24 is attached to a lower end of the shock strut 10. The aircraft structure 20, attachment member 22, and wheel assembly 24 are shown in simple or outline form, while other structures such as locking mechanisms and retracting
30 mechanisms are not shown in FIG. 1 in order to avoid obscuring the shock strut. Various arrangements of such structures are known in the art and are not critical to the description or understanding of the invention.

The shock strut 10 includes a piston 30 and a cylinder 32 which may be cylindrical as is customary, or some other shape if desired. The cylinder and piston respectively have one or more mounting tabs (eyes) 33 and 34 for attachment to the aircraft structure 20 and the wheel assembly 24. The piston 30
5 communicates forces to and from the wheel assembly 24. The cylinder 32 receives the piston 30 in a manner that permits relative telescoping movement between the cylinder 32 and the piston 30 to absorb and dampen shock forces from being transmitted to the aircraft structure 20.

In accordance with the present invention, a sensor assembly or detector 35
10 is provided for sensing or detecting a condition of a level of a liquid contained within the strut 10 (as in the manner hereinafter described) and outputting a signal related to the liquid level. In the illustrated embodiment, the detector 35 includes a probe assembly 37 extending into the strut and a transmitter/receiver or sensor unit 38 located outside the strut for transmitting/receiving signals to/from the
15 probe assembly. The sensor unit 38 communicates the signal from the probe assembly 37 to a computer, processor or other logic device 39 for analyzing the signal and for determining a condition of the amount of liquid in the strut 10.

The processor 39 may have a memory and software associated therewith to carry out monitoring operations, and may be located near the strut 10, may be
20 remote from the strut or may be a combination with some processing and/or data storage occurring near the strut and other processing and/or data storage occurring at another location. The processor also may be coupled to a display (not shown), which may be on the flight deck or in the wheel well, or may be connected by maintenance personnel as needed. The processor 39 can
25 communicate with the sensor unit 38 via an electric or optical cable 40, or by other means such as a radio frequency transmitter and receiver, or other device.

While the sensor unit 38 may be connected to the processor 39 via electrical means, preferably the probe assembly 37 is an optical device that communicates with the sensor unit 38 via an optical cable 41. This
30 advantageously avoids introduction of electrical signals into the interior of the strut. Although a capacitance sensor can be used to determine how much liquid remains in the strut 10, generally this is not desirable.

Referring now to FIG. 2, the piston 30 and the cylinder 32 of the shock strut 10 define a sealed elongate chamber 42 at least partially filled with a liquid, such as hydraulic fluid or oil. The liquid preferably is filled to a nominal or full level, indicated by the line 44. A portion of the chamber 42 is filled with a gas, such as nitrogen, as is common in an air-over-oil type of shock strut. The gas generally is pressurized and the chamber 42 is sealed to provide a pressurized environment inside the chamber relative to the atmosphere outside the strut 10. Various sealing arrangements that allow telescoping movement between the piston 30 and the cylinder 32 while maintaining a seal are well known.

The illustrated shock strut 10 also includes an orifice plate 50 within the chamber 42 that has an orifice opening 52 passing therethrough. The orifice plate divides the chamber 42 into a pneumatic chamber 54 that has a gas in the upper portion thereof and a dynamic liquid chamber 56 that is partially defined by the piston 30 and which generally is filled with a liquid. The latter chamber may be referred to as the dynamic oil chamber 56, since oil often is used as the liquid.

A metering tube 58 may be mounted in the pneumatic chamber 54 between an end wall of the cylinder 32 and the orifice plate 50. A metering pin 60 is mounted to the end of the piston 30 and extends into the orifice opening 52 as the piston 32 is telescopically compressed into the cylinder 30. The metering tube 58 guides the metering pin 60 and generally keeps the pin centered in the orifice opening 52. The metering pin 60 regulates the size of the area through which the liquid can flow, thereby increasing the resistance to further compression and regulating the extension of the piston 30 when the compression force is removed or reduced.

In FIGS. 2 and 3, details of an exemplary detector 35 are shown. The probe assembly 37 includes at least one probe 80/82, and the cable 41 for connecting the probe or probes to the sensor unit 38. The cable is sealed by a pressure fitting assembly 72 to the wall of the strut 10 at an opening in the wall through which the probe assembly 37 passes. A guide tube 74 is mounted by suitable means within the chamber 42, and preferably extends from the interior or pressurized end of the pressure fitting assembly 72. The pressure fitting and guide tube are discussed below in greater detail.

In the illustrated embodiment, the probe assembly 37 includes two probes 80 and 82. The probe 80 functions to detect the presence or absence of liquid at a first location, indicated at 84. The second probe 82 functions to detect the presence or absence of liquid at a second location, indicated at 86, which
5 represents a lower liquid level that may be outside the range of specified acceptable liquid levels. For example, when liquid is no longer detected at the first liquid level 84, an indication may be given that the strut should be serviced, perhaps within the month. When liquid is no longer detected at the second, lower liquid level 86, an indication may be given that the strut needs service sooner,
10 perhaps right away before the next flight or within the week. Such detection can be effected by sensing either the presence or absence of liquid at a given level, depending on the type of probe and its orientation relative to the fluid level in the strut.

As above mentioned, the probes 80 and 82 preferably are fiber optic
15 probes. The sensing end or tip of each probe includes a retro-reflector or retro-reflective corner cube prism exposed to the fluid in the pneumatic chamber 54. When the tip of the probe is covered by liquid, the amount of light reflected is minimal or zero because the relative indices of refraction of the liquid and the tip of the probe are similar. However, in the absence of liquid, a light signal
20 transmitted from the sensor unit 38 to the probe is substantially completely reflected, thereby indicating the absence of liquid at the tip of the probe.

An exemplary sensor unit 38 is the Mini Beam™ system from Banner Engineering Corporation of Minneapolis, Minnesota, USA. The sensor unit 38 interfaces electrically or electronically with the processor 39. The sensor unit 38
25 also acts as a transmitter/receiver that sends and receives optical or light signals to and from the fiber optic probe assembly 37 along respective optical leads or fibers 73.

The probes 80 and 82 are connected to the sensing unit 38 by the cable 41 which includes optical fibers 73 for channeling light from the sensing unit 38 to
30 the probes 80 and 82 and reflected light from the probes 80 and 82 to the sensing unit 38. In the illustrated embodiment, the optical fibers 73 are continuous, but it

will be appreciated that each fiber may be composed of two or more segments that connect the sensing unit 38 to the probes 80 and 82.

In the illustrated embodiment, proper positioning of the probes 80 and 82 within the chamber 42 is effected by the guide tube 74. The guide tube 74 also
5 helps keep the probes 80 and 82 and the optical fibers 73 within the chamber 42 away from moving parts of the strut 10. However, other means for positioning and restraining the probes 80 and 82 could be used in place of the guide tube 74. The guide tube 74 also facilitates installation and/or replacement of the probe assembly 35 as will be explained in a subsequent paragraph.

10 The lower end of the guide tube 74 preferably is submerged in the liquid in the chamber 42 and has a bottom opening and/or several lateral openings 83 communicating with upper portion of the chamber 42, thereby to allow the liquid to pass into and out of the guide tube 74 for contacting the probes 80 and 82 allowing the level in the guide tube to assume the same level as the balance of
15 the liquid in the balance of the chamber 42. The guide tube 74 has a diameter which is much less than the diameter of the chamber 42, and thus the liquid in the guide tube is subject to less wave action and reduced amplitude wave action in response to shock and vibration forces applied to the shock strut 10. However, liquid sensing usually will take place when the aircraft is in flight and the landing
20 gear are extended, at which time wave action will be minimal. An exemplary guide tube 74 has a diameter of about three-quarters of an inch (about 1.9 cm) and has a length of about eighteen inches (about 45.7 cm).

The guide tube 74 has one or more spring tabs 90 that hold the guide tube 74 in place in the chamber 42, although other means for securing the guide tube
25 could be used, including a welded attachment, bolts or rivets. In the illustrated embodiment, several spring tabs 90 help brace the guide tube 74 between the wall of the cylinder 32 and the metering tube 58. As seen in FIGS. 3 and 4, the upper end of the guide tube 74 is flared for closely mating with a tapered end of a tubular fitting 94 forming part of the fitting assembly 72.

30 The illustrated pressure fitting assembly 72 includes the tubular fitting 94 that is mounted, as by threading, in a threaded hole 92 in the wall of the cylinder

32. A packing (not shown) or other suitable sealing means may be interposed between the fitting 94 and the sides of the hole 92 to provide a further seal.

The tubular fitting 94 has a through passage 96 in which a plug 98 is received and sealed by an O-ring 106 or other suitable means. In particular, the
5 plug 98 has an annular groove 104 for receiving the O-ring 106 for providing a sealed interface between the plug 98 and the fitting 94. The through passage 96 and plug 98 preferably are cylindrical. The plug 98 is located between a shoulder 108 formed by a reduced diameter end portion of the through passage 96 and a retainer 100 that is screwed into or otherwise removably fastened to the fitting 94
10 for retaining the plug 98 in the fitting. Both the fitting 94 and the retainer 100 may be provided with hexagonal head portions to facilitate installation. Also, an annular seal and/or washer 110 may be interposed between a head flange of the retainer 100 and outer end surface of the fitting 94, as shown. In an alternative arrangement, the fitting 94 could be formed as an integral part of the cylinder 32,
15 in which case it obviously would not be removable.

The plug 98 preferably is molded to the cable 41. More particularly, the plug is molded directly to the optical fibers 73 passing therethrough. The optical fibers are transversely spaced from one another so that each fiber is surrounded by the plug material molded thereabout. This arrangement provides an effective
20 seal between the plug 98 and each fiber 73 without significantly degrading the operation (preferably no greater than 10% light transmission degradation) of the optical fibers. Although less desirable, the plug 98 could be molded directly to a sheath on the optical fiber.

Externally of the fitting assembly 72, the optical fibers are protected by a
25 sheath 112. In FIG. 4, the sheath 112 is shown broken away, but preferably extends into a through bore 114 in the retainer 100 through which the optical fibers 73 pass. The optical fibers 73 extend from the fitting 94 into the guide tube 74 and terminate at the probes 80 and 82 for conveying signals to and from the sensor unit 38 (FIG. 2) as above described. The fibers 73 can be individually
30 sheathed, or as shown the fibers associated with a respective probe can pass through a protective tube 116.

As will be appreciated, the foregoing arrangement enables easy replacement of the probe assembly 35. To remove the probe assembly, the retainer 100 is removed from the fitting 94. This allows the entire probe assembly 35 to be withdrawn from the guide tube 74 by simply pulling the plug 98 and
5 optical fibers 73 out of the fitting 94 and the guide tube. A replacement assembly can be installed in a reverse manner, inserting the optical fibers 73 with the probes 80 and 82 at the end thereof into the guide tube 74 which guides the optical fibers and the probes into position and finally pushing the plug 98 into the fitting 94, after which the retainer 100 can be reinstalled. It is noted the reduced
10 diameter portion of the through passage 96 in the fitting 98 is sized to permit passage therethrough of the optical fibers 73 and any protective sheathing or tubes 116.

A gas fitting (not shown) also may be provided in the wall of the cylinder 32 to provide access for a pressure transducer and the addition of gas. Pressure
15 data developed by the transducer also can be communicated to the processor 39.

In operation, compression of the shock strut 10 causes the piston 30 to move into the cylinder 32 thereby reducing the volume of the chamber 42 and compressing the portion filled with gas. The compressed gas stores energy in a manner similar to a spring. Relative telescoping movement of the piston 30 into
20 the cylinder 32 pumps liquid from the generally lower dynamic liquid chamber 56 through the orifice plate 50 into the pneumatic chamber 54 as the shock strut 10 is compressed, thereby increasing resistance to compression through fluid amplification while simultaneously dissipating compression energy. As the piston 30 moves into the cylinder 32, the metering pin 60 moves into the orifice opening
25 52 in the orifice plate 50, effectively reducing the flow area through the orifice opening 52 and increasing resistance to further compression.

Part of the work expended in compressing the shock strut 10 is stored as recoverable spring energy in the portion filled with gas which resiliently suspends the aircraft structure 20 (FIG. 1) while taxiing on the ground, and which also
30 allows the piston 30 and the cylinder 32 to return to an extended position after the compression force is removed, such as after takeoff.

The detector 35 monitors the liquid level. As above indicated, usually such monitoring is effected when the aircraft is in flight and when the strut 10 is in a fully extended position, as when the landing gear are extended. When the liquid level drops below the threshold level 84 or 86 as sensed by the detector 35, the processor 39 may initiate an audible, visual or other alarm for alerting personnel to check the liquid level.

Specifically, the system detects the condition of the liquid level when the strut 10 is in a fully extended position and the aircraft is in flight. This avoids the need to compensate for the change in liquid level that occurs when the strut is compressed, i.e., not fully extended. Since the strut reaches the fully extended position once the aircraft leaves the ground for flight or when the strut is deployed in preparation for landing, the probes 80 and 82 are best positioned to determine the condition of the liquid at those times.

The processor 39 may receive a signal indicating that the aircraft has left the ground or that the landing gear has been deployed for landing. At that time, the processor 39 would activate the sensor unit 38 to send a beam of light through the optical fibers 73 to each probe 80/82. In the absence of liquid, the light will be reflected back through the return fiber. In the presence of liquid, no light is reflected. The sensor unit 38 indicates whether return light was observed and this is communicated to the processor 39. Reflected light received from both probes 80 and 82 indicates the liquid level is unacceptably low. Reflected light received from only the shorter probe indicates that the liquid is low but still acceptable. Minimal reflected light would indicate that the strut 10 has the proper fluid level. The processor 39 stores the data for retrieval by maintenance personnel and/or may provide an alert, such as illuminating a light in the cockpit to be observed by flight personnel and/or in the wheel well to be observed by the ground crew after the flight and/or before the next flight. Those skilled in the art will also appreciate that additional probes may be used to provide additional level readings as may be desired.

Although the invention has been shown and described with respect to certain illustrated embodiment, equivalent alterations and modifications will occur to others skilled in the art upon reading and understanding the specification and

the annexed drawings. For example, although an embodiment of the invention directed to an aircraft strut is described, a shock absorber provided by the present invention may have other applications other than aeronautical applications. In particular regard to the various functions performed by the above described

5 integers (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such integers are intended to correspond, unless otherwise indicated, to any integer which performs the specified function (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein

10 illustrated embodiments of the invention.